Proposal for MI Injection and Extraction Kickers

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INTRODUCTION In this note, basic magnet and power supply designs are considered which should meet the performance criteria spelled out in MI-15 KICKER SPECIFICATIONS by D. Johnson. In all cases, a 2x4 inch aperture is used. While the aperture increase would preclude using any of our existing magnets as is, they may provide a valuable source of components for new counterparts.

A summary of the relavant design parameters taken from the above publication with the exception of the P-bar injection kicker rise and fall times is as follows:

PARAMETER	Proton Inj.	P-bar Inj.	Proton Ext.	P-bar Ext.
Available space	5.35 meters	3.35 meters	5.35 meters	5.35 meters
$\int Bdl$	0.4kGm	0.383kGm	2.625kGm	2.625kGm
Flattop $\Delta B/B$	1%	2.4%	1%	1%
Vert. Aperture	5.08cm	5.08cm	5.08cm	5.08cm
Horiz. "	10.16cm	10.16cm	10.16cm	10.16cm
Field T_r	38nSec	NA	1.48uSec	9.6uSec
Flattop	1.6uSec	1.6uSec	9.6uSec	1.6uSec
Field T_f	38nSec	9.6uSec	NA	NA

In the computation of the required magnet parameters, 1.27cm has been added to the vertical aperture to include space for the beam tube. Current requirements are based on a gap profile of 6.35cm by 10.16cm.

PROTON INJECTION KICKER: The primary constraint on this design is the rise and fall times. To achieve the fastest possible field propagation time for the magnet, the highest practical impedance should be used. In this case, a 50 ohm ferrite loaded traveling wave magnet is recommended. For reliable operation, the PFL (pulse forming line) operating voltage should be limited to a nominal 60kV. This sets the magnet current to 600A per magnet. With a pole tip spacing of 6.35cm, the peak field in the gap will be 119 Gauss and the magnetic length 3.37 meters which will fit well within the space alloted even with the additional length required for connections. If the decision is made to use 4 magnets, each will have a magnetic length of 84cm and a physical length of 1.2 meters which still should fit in the alloted space. A typical magnet would be made up of 24 cells each having a series inductance of 35.5nH and a shunt capacitance of 14 pF. The fill time of such a magnet would be:

$$(1) \quad T_{fill} = N\sqrt{LC}$$

where N is the number of sections, L is the inductance per section and C is the capacitance per section. For this design the propagation time is 17nSec. The rise time (1 to 99%) of the field in a typical section can be approximated by:

$$(2) \quad T_r = 2.42(N)^{1/3}\sqrt{LC}$$

which for this design is 5nSec.

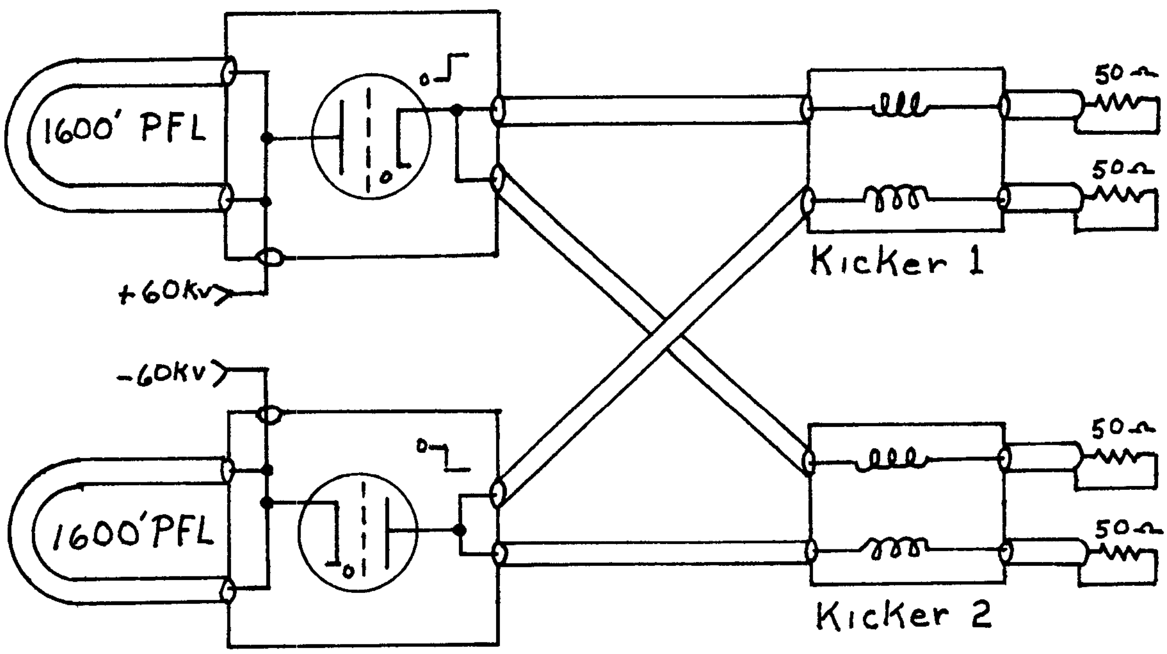
To attain a cell inductance of 35.5nH, it becomes necessary to use a picture frame design and pulse each side of the magnet with opposite polarity pulses. This is analogous to having two C magnets each having half the pole tip width on opposite sides of the gap. It enables us to use twice the peak power to drive flux into the gap without increasing the physical length of the system.

The proposed traveling wave magnet design is summarized as follows:

Aperture	5.08cm x 10.16cm
Gap height	6.35cm
Pole tip width	10.16cm
Magnetic length	84cm
Physical Length	120cm
Z_o	50 ohm
Peak current	+/-600 Amps
Peak field	119 Gauss
Field fill time	17nSec
Field rise time	5nSec

The pulser for this system would be similar to that built for SLAC which uses 2 EEV 1671D thyratrons in two parallel 25 ohm systems. For our system, one of the tubes would be reversed and the PFL connected to the cathode as shown in figure 1. As indicated, these pulsers would drive two magnets. An obvious advantage to this approach is that it is a proven design which only requires physical modification. The current rise time of this pulser is about 20nSec which would produce a field rise time of 21nSec which when added to the field fill time results in a 38nSec time to reach full field throughout the length of the magnet.

Each PFL would be a 1060 ft length of a 2 inch coax design copied by Times Wire from the F&G cable used on the SLAC kicker PFL. This cable has a 3 ft minimum bending radius, so carefull consideration must be given to its placement. When charged to 60 kV, each PFL will contain 58 joules of energy.



Proton Injection Kicker

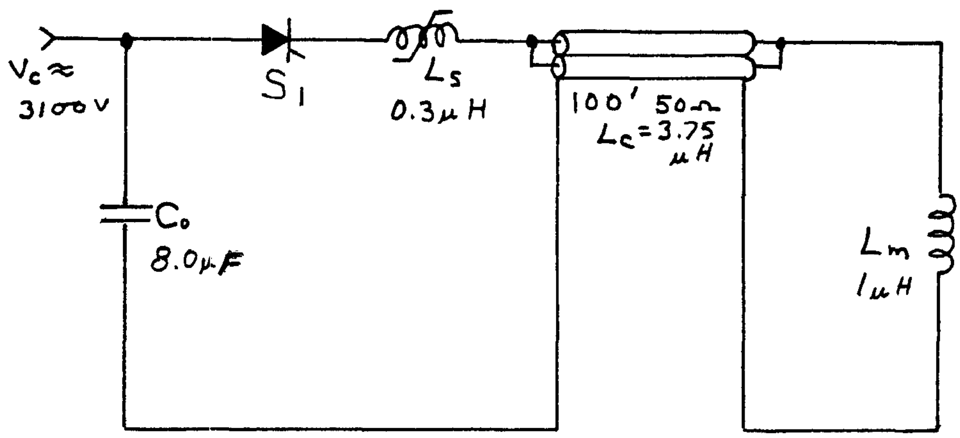
Figure 1

ANTIPROTON INJECTION KICKER: This magnet would be very similar to our present E17K1 main ring extraction kicker. A single magnet of .5 meter magnetic length would require 3860 amps to produce the required 764 gauss. Such a magnet would have an inductance of 1.0uH.

This proposed magnet design is summarized as follows:

Aperture	5.08cm x 10.16cm
Gap height	6.35cm
Pole tip width	10.16cm
Magnetic length	0.5 meter
Physical length	.85 meters
Inductance	1.0uH
Peak current	3860 Amps
Peak field	764 Gauss
Field rise time	<9.6uSec
Field fall time	<9.6uSec
Flattop	1.6uSec

The field rise and fall time requirements coupled with a 2.4% field tolerance during flattop suggest a half sine pulse. A field error of less than 1% can readily be achieved with a half sine pulse having a base width of 20 uSec. The pulser design shown in figure 2 uses the inductances of the cables which power the magnet as part of the resonant circuit. If two lengths of RG-220 coax are paralleled for a 100 ft run between magnet and pulser, then the required current pulse can be generated with an 8uF capacitor charged to 3100 volts. This means that the switch could be either a small thyratron or thyristors. The stored energy in the system is about 40 joules.



P-Bar Injection Pulser

Figure 2

<u>PROTON EXTRACTION KICKER</u>: This magnet design will be similar to the D48 kicker magnet. A single magnet is used which has a magnetic length of 2 meters. The field will be 1.31kG which will require a 6.64kA current pulse. To meet the field rise time requirements, a ferrite loaded traveling wave design is required. A system having a 5 ohm impedance will require a magnet voltage of 34kV which seems reasonable.

A magnet two meters in length would be made up of 56 cells (1.4 inches in physical length) each having an inductance of 71.8nH and a shunt capacitance of 2.87nF. Equations (1) and (2) show that for this design, the field propogation time is 804nSec and the field rise time in a cell is 133nSec. If a pulse current rise time of 100nSec is assumed, the field should be at its maximum value throughout the kicker in 970nSec. This is well within the requirements given for this kicker. The proposed traveling wave magnet design is sumarized as follows:

Aperture	5.08 x 10.16cm
Gap height	6.35cm
Pole tip width	10.16cm
Magnetic length	2 meters
Physical length	2.4 meters
Z_o	5 ohms
Peak current	6.64kA
Peak field	1313 Gauss
Field fill time	804nSec
Field rise time	133nSec

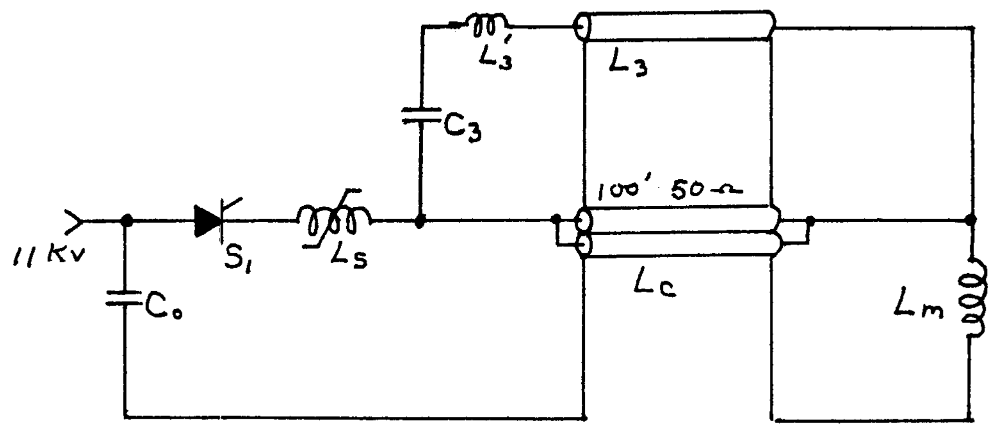
In order to generate a 9.6uSec flattop pulse, a 5 ohm lumped element PFN will be required to operate at 68kV. If the pulse is to be flat to within 1%, 20 to 30 sections will be required. Care must be taken in the design of this low impedance PFN to insure that stray inductances do not change the actual response of the system.

The switch should be a four gap thyratron such as the EEV CX-1193B which is the high current double ended tube used in the D48 kicker.

ANTIPROTON EXTRACTION KICKER: While the field requirements for the proton and antiproton extraction kickers are the same, the dissimilarities in their rise times make them totally different designs. The antiproton extraction kicker magnet would be a 2 meter version of the antiproton injection kicker following the E17K1 design. Its design parameters are summarized as follows:

Aperature	5.08cm
Gap height	6.35cm
Pole tip width	10.16cm
Magnetic length	2 meters
Physical lengt	2.4 meters
Inductance	4.02uH
Peak field	1313 Gauss
Peak current	6.64kA
Field rise time	<9.6uSec
Flattop	1.6uSec

The field rise time of 9.6uSec suggests the use of a half sine pulser to meet the design requirements. The design field of 1.313kG will require a 6.64A peak current pulse. To safely meet the specifications, however, the third harmonic design shown in figure 3 is recommemded. The circuit uses the inductances of the magnet power cables as part of two resonant circuits. When switch S_1 closes, the voltage on C_o is applied to the primary current loop made up of L_s, L_c, and L_m. The voltage drop across L_c induces a current in the secondary resonant loop made up of L_c, L_3, and C_3. This secondary loop resonates at the third harmonic of the primary loop. Its current couples into the primary loop through the common reactance of L_c. The relative impedances determine the magnitude and the phase of the third harmonic. To safely meet the requirements of this system, only a small amount of third harmonic is required so the magnitude and phase will not be critical. Approximately 11 kV is required on the capacitor bank. To switch this voltage one still might consider using thyristors, but certainly the single gap double ended thyratron used in some of the the E17 kickers would do the job. SPICE modeling of such a system indicates that it is possible to achieve a flattop of 0.25% for 2uSec with very little effort with this design. See figure 4.

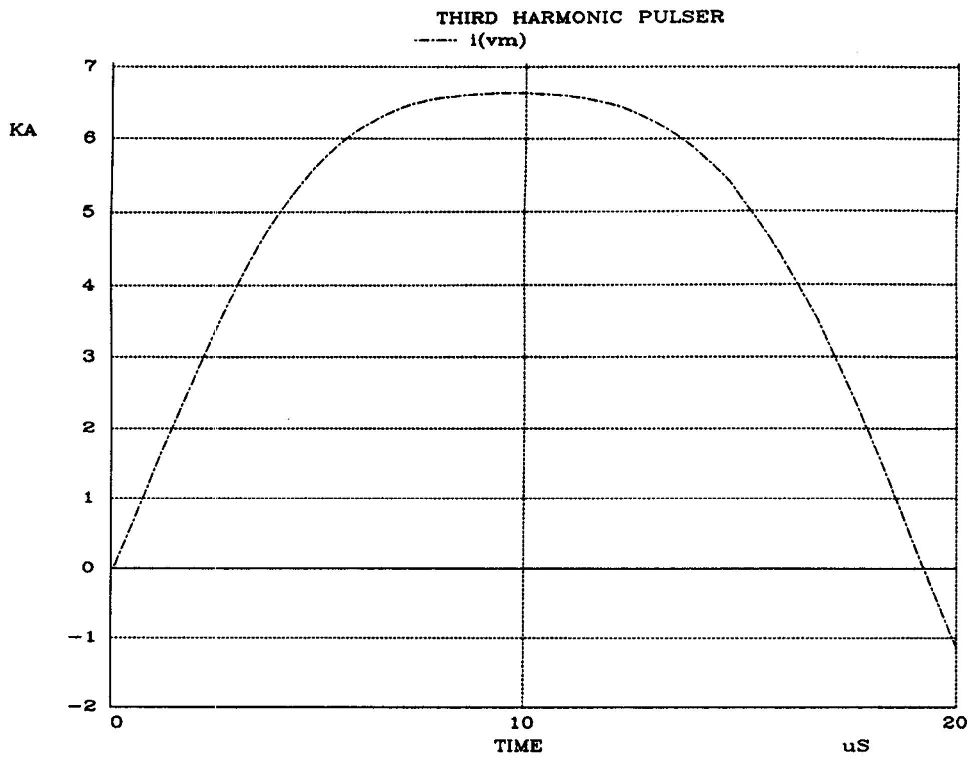


Third Harmonic Pulser for P-Bar Extraction

Figure 3

<u>CONCLUSIONS</u>: While the increased aperture of the MI precludes using any of our existing kicker magnets as is, many of the designs and possibly some components as well can be carried over to the new magnets. The one exception is the proton injection kicker magnet. The rise and fall time requirements for this system are much faster than for the kicker built for SLAC and almost 10nSec faster than the LEB extraction kicker for the SSC. While calculations indicate that it is possible to achieve the desired rise time, dispersion in a practical system may well prevent us from achieving the desired fall time. This should not be a problem since the 38 nSec given in the original specification refers to two missing bunches and does not take into account the fact that the beam is damped around the synchronous phase angle and therefore does not occupy the entire phase stable area. This fact should add an additional 10 to 12 nSec to the rise and fall time limits.

Most of the other kickers are straight foreward designs. However, considerable engineering effort will be required to develop them into reliable systems.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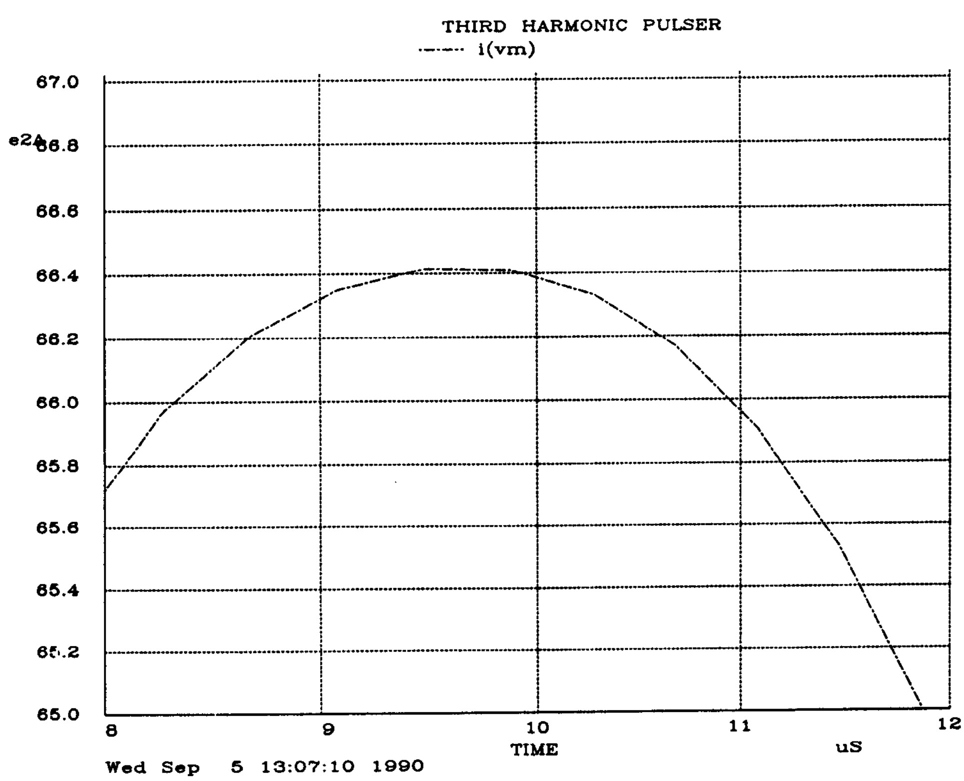
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Figure 4